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The Spore Discharge of the Apple Scab Fungus in Delaware

BY

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Newark, Delaware

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THE SPORE DISCHARGE OF THE APPLE SCAB FUNGUS IN DELAWARE

J. F. Adams

There has been observed considerable variation in the prevalence of apple scab infection between the commercial orchard sections of Kent and Sussex Counties, Delaware, which are within thirty-five miles of each other. Kent County is much the older orchard section of the two, and the disease has been under control for a longer period of time than in Sussex County. This difference in length of control has been considered by some growers to account for the smaller prevalence of apple scab infection generally observed in Kent County.

Studies were undertaken to determine the discharge of ascospores in relation to spring infection of apple scab in the two counties. It was considered that such studies might give information to account for the variation in prevalence as well as assist to better relate spraying schedules to infection periods of the apple scab disease.

The Life History of the Apple Scab Fungus

The disease is so generally familiar to the commercial orchardists that a description of the symptoms is not essential. The nature of the fungus or organism as regards its seasonal activity is briefly described in order to explain the results upon which these studies are based.

The apple scab disease is caused by a fungus that is parasitic because it depends upon the living apple host to secure its food for existence. It reproduces and spreads by means of spores or seed like bodies. There are two kinds of spores which for convenience may be called summer and winter spores. The summer spores are produced most abundantly and cause the olive green appearing spot of infection that is found on the fruit, leaves, and stems of the apple. The dissemination of these spores is associated with the infections produced during the growing season and account for what is generally called secondary infections, which are most commonly found on the fruit. The winter spore stage develops in the overwintered leaves which were infected during the previous summer. They are found within flask shape structures called perithecia. Within these structures are sac-like growths called asci, in which the spores are formed. The

spores formed in these asci are called ascospores or winter spores. It is the ascospores or winter spores which, for the most part, are the cause of the scab infections during the spring. The ascospores are "shot out" of the perithecia and they are carried and distributed for some distance by air currents.

Since the discharge of the ascospores can be easily studied, it is apparent that their relation to the spring infection on the apple tree may explain the periods of infection and also the relation and efficiency of fungicide applications to control.

Ascospores are discharged in large numbers under certain favorable conditions; but only a small percentage of them produce infection as compared to the total number discharged. The number of ascospores from a single leaf may account for serious infection on a single tree. Wallace (1913) states that "from a fragment of leaf one centimeter square 5630 spores were discharged in forty-five minutes. From this it is estimated that if the surface of the ground beneath trees set 40 x 40 feet apart were covered with old leaves well infected with perithecia, there might be 8,107,200,000 ascospores discharged for each tree in forty-five minutes in wet weather. Certainly this would be sufficient to account for abundant early infection, even though only a very small percentage of these ascospores would reach the trees and actually produce infection." Curtis (1921) in New Zealand says that "admitting the (low) averages of 200 perithecia and eight ascospores per ascus, the average yield in ascospores per leaf is 64,000. In carefully tended orchards, many leaves from the majority of the trees develop perithecia. In a heavily infected leaf there may be 500 or more perithecia to the square inch of leaf surface, and in one case more than 1300 perithecia occurred in a square inch." Keitt and Jones (1925) determined the frequencies of ascospores in orchard air, by means of a motor driven suction apparatus and a suitably arranged filter. The maximal occurrence of ascospores was recorded May 13, 1923, when during a rain they were caught through a four-hour period at the average of 289 ascospores per cubic foot of air. The major portion of the season's discharge occurred before the blooming period at Sturgeon Bay, Wisconsin. Studies in Delaware have shown during periods of maximum daily spore discharge as many as 600-800 ascospores from some leaves.

Method Used for Studying Ascospore Discharge

Old scab infected leaves overwintering under trees in the orchard were selected for this study. Five leaves were used for each experiment in 1922 and three in 1923. They were

placed on the ground which was packed so that no washing of dirt would interfere with spore discharge. This exposure was similar to overwintered leaves under natural conditions which are not disturbed by cultivation. Two matches were used to assist in keeping the leaf flat on the ground. These were placed, one at the tip and one at the base of each leaf. The ends of the matches were anchored to the ground by wire loops made from paper clips. Microscopic glass slides, one side of which was smeared with a white mineral oil were placed oiled side down over the leaf. The matches supported the slides and their thickness allowed a small air space between the leaf and oiled surface of the slide. The glass slides were replaced daily following twenty-four hour exposure regardless of weather conditions. The entire exposed surface of each slide was examined under low power of the microscope. When spores were located a count was made from a high power field and the average number of spores found in five high power fields were estimated. Such a record indicated only the relative amount of spore discharge. For convenience of illustrating the spore discharge, it is indicated as light, medium and heavy in Figs. I, II, III and IV.

When the spores were discharged from the leaves they were caught on the oiled surface of the slide. Their adherence in the oil film indicated to a certain extent the manner of the spore discharge. Opinions are divided as to the manner of ascospore expulsion. Some investigators consider the ascospores are extracted out of the asci into the perithecium and then "shot out" of the perithecium. Cunningham (1921) in New Zealand as the result of his studies considers that in the presence of abundant moisture, the whole perithecium explodes, discharging asci, and spores with some violence, leaving only the basal portion of the perithecium embedded in the tissue. During the course of the slide examinations no instance was found where asci had been expulsed. In some instances the mass of ascospores in a single area indicated expulsion of the possible majority of spores in a perithecium. However, the studies further brought out that there was no uniformity in maturing of perithecia or expulsion of ascospores from a single leaf.

There is no definite incubation period from the time of infection through to the symptoms of the disease or signs of the fungus. Temperature and moisture conditions are the governing factors. A period of seven to eighteen days may intervene between the time of infection by ascospores and the familiar greenish growth of the fungus appearing on the surface of the fruit and leaves.

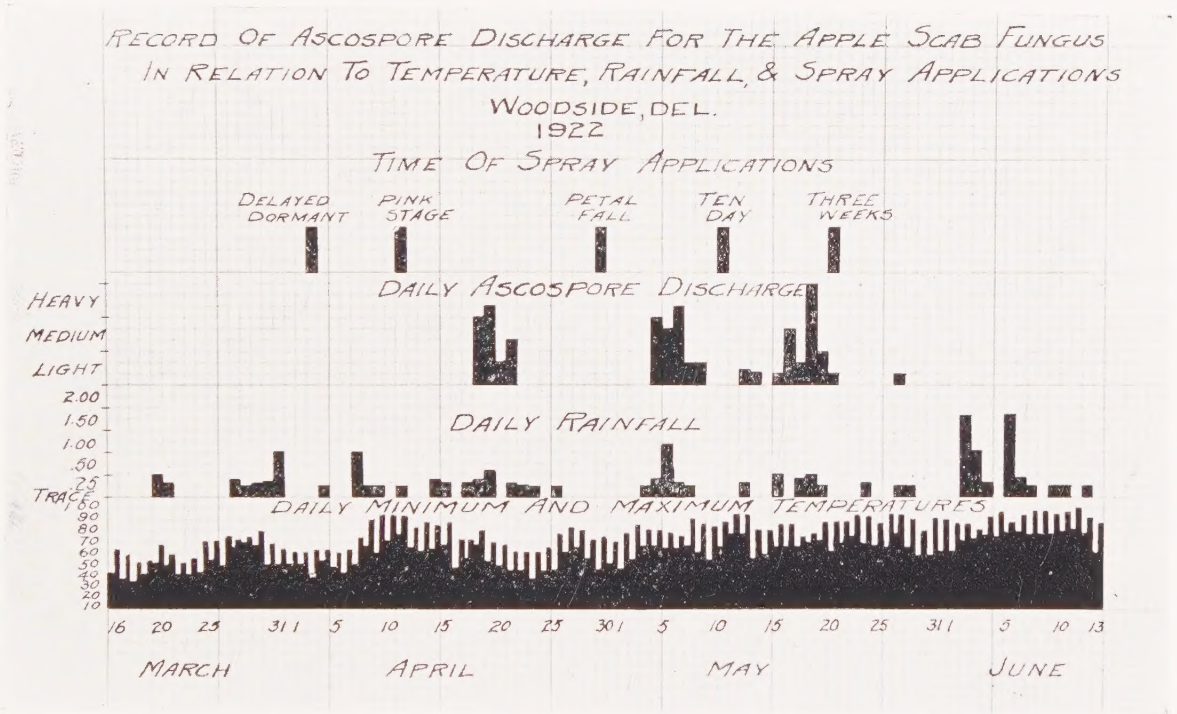

RECORD OF ASCOSPORE DISCHARGE FOR THE APPLE SCAB FUNGUS
IN RELATION TO TEMPERATURE, RAINFALL, & SPRAY APPLICATIONS
WOODSIDE, DEL.
1922
TIME OF SPRAY APPLICATIONS
DELAYED DORMANT
PINK STAGE
PETAL FALL
TEN DAY
THREE WEEKS
DAILY ASCOSPORE DISCHARGE
HEAVY
MEDIUM
LIGHT
DAILY RAINFALL
2.00
1.50
1.00
.50
.25
TRACE
DAILY MINIMUM AND MAXIMUM TEMPERATURES
16 20 23 31 1 5 10 15 20 25 30 1 5 10 15 20 25 31 1 5 10 13
MARCH
APRIL
MAY
JUNE

FIG. I

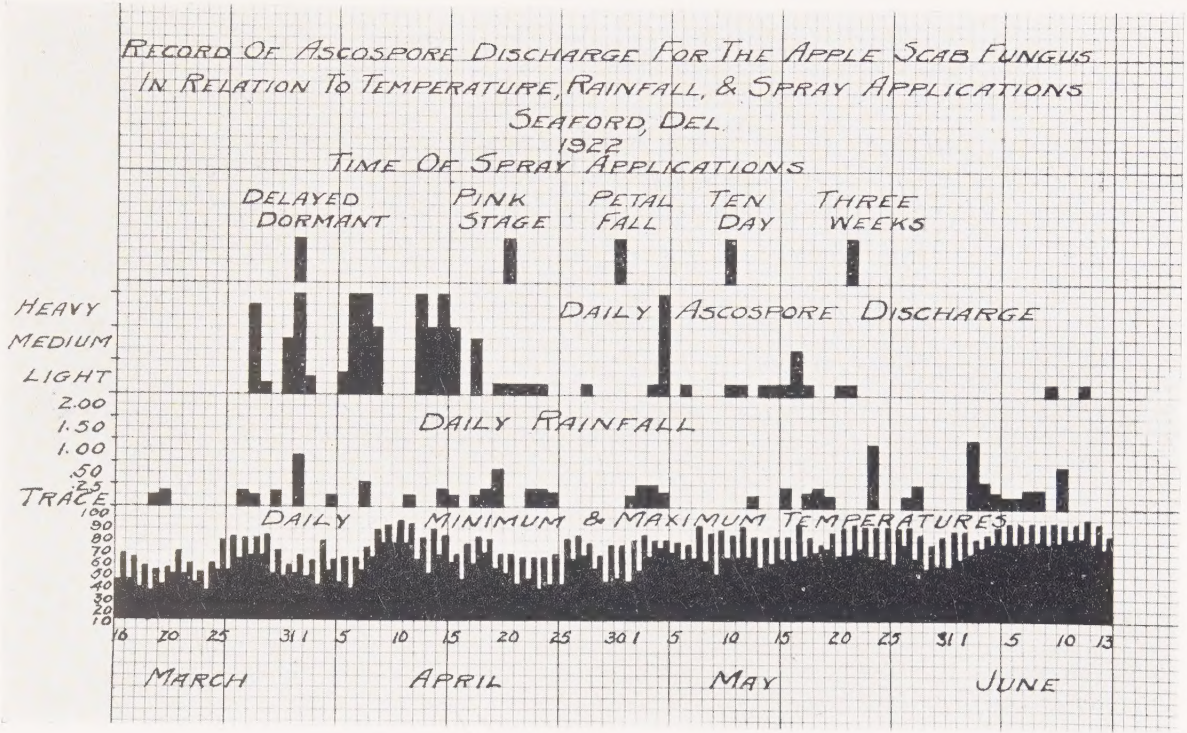
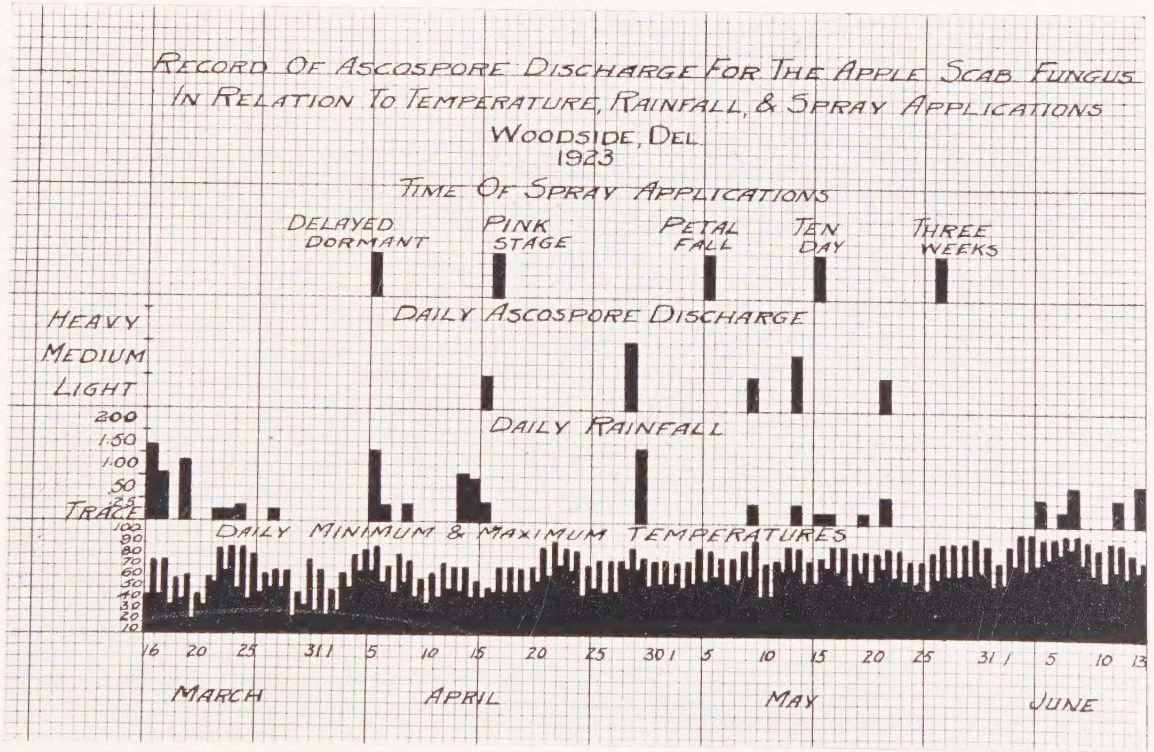

RECORD OF ASCOSPORE DISCHARGE FOR THE APPLE SCAB FUNGUS
IN RELATION TO TEMPERATURE, RAINFALL, & SPRAY APPLICATIONS
SEAFORD, DEL.
1922
TIME OF SPRAY APPLICATIONS
DELAYED DORMANT
PINK STAGE
PETAL FALL
TEN DAY
THREE WEEKS
HEAVY
MEDIUM
LIGHT
DAILY ASCOSPORE DISCHARGE
2.00
1.50
1.00
.50
.25
TRACE
DAILY RAINFALL
100
90
80
70
60
50
40
30
20
10
DAILY MINIMUM & MAXIMUM TEMPERATURES
16 20 25 31 1 5 10 15 20 25 30 1 5 10 15 20 25 31 1 5 10 13
MARCH
APRIL
MAY
JUNE

FIG. 11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WOODSIDE, DEL.
1923
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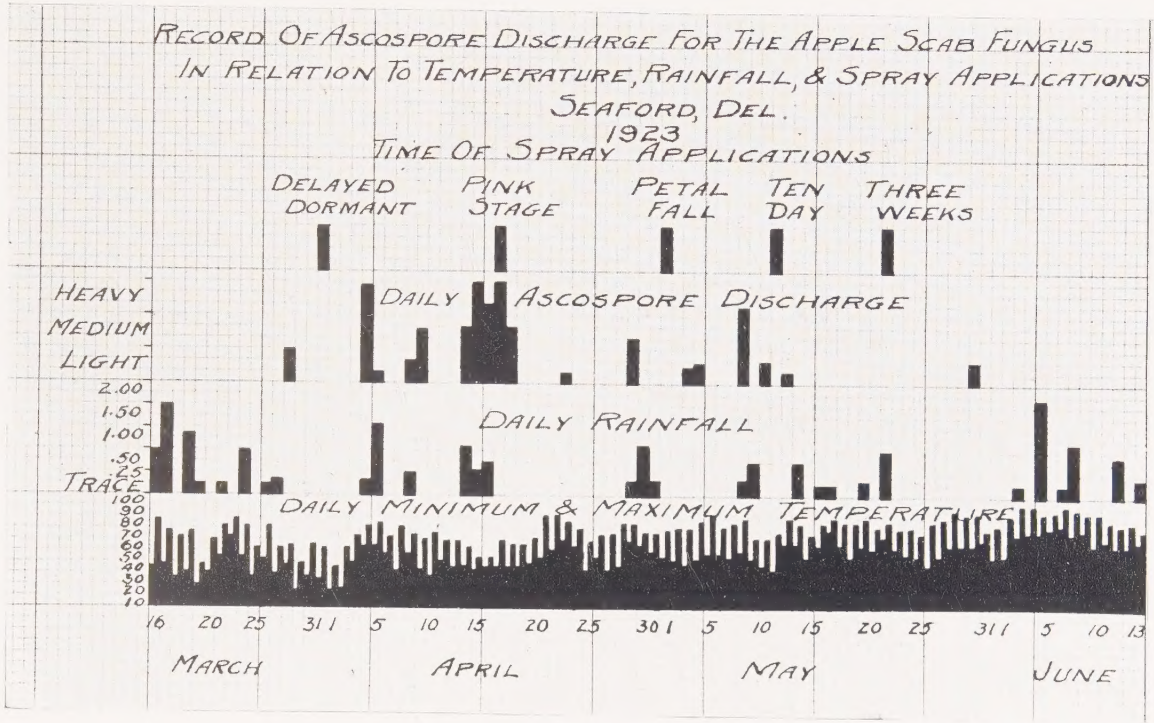
DELAYED DORMANT
PINK STAGE
PETAL FALL
TEN DAY
THREE WEEKS
DAILY ASCOSPORE DISCHARGE
HEAVY
MEDIUM
LIGHT
DAILY RAINFALL
2.00
1.50
1.00
.50
.25
TRACE
DAILY MINIMUM & MAXIMUM TEMPERATURES
100
90
80
70
60
50
40
30
20
10
16 20 25 31 1 5 10 15 20 25 30 1 5 10 15 20 25 31 1 5 10 13
MARCH
APRIL
MAY
JUNE

FIG. III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1.50
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.25
TRACE
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30
20
10
DAILY MINIMUM & MAXIMUM TEMPERATURE
16 20 25 31 1 5 10 15 20 25 30 1 5 10 15 20 25 31 1 5 10 13
MARCH
APRIL
MAY
JUNE

FIG. IV

The earliest evidence of the disease has usually been observed on the lower surface of the small juvenile leaves in the opening blossom buds. The disease is later found on the petals, fruit, pedicel and leaves of the developing blossom buds. Since the leaf buds open and develop later, the leaves on the new shoot growth usually show more evidence of infection. There are a greater number of leaves on the shoot growth to be exposed to infection than from the blossom buds.

ASCOSPORE DISCHARGE OF THE APPLE SCAB FUNGUS DURING 1922 AND 1923

The investigational studies on ascospore discharge at Woodside, Kent County, and Seaford, Sussex County, were correlated with, temperature, rainfall, and the growth periods of the apple trees. The main results of these studies are summarized in Figs. I, II, III and IV.

At Woodside, the studies were started March 28, 1922, and March 23, 1923, and were completed May 27, 1923, and June 12, 1923, while at Seaford they were started March 17, 1922, and March 8, 1923, and completed June 4, 1922, and June 18, 1923. Ascospore discharge has been reported by other investigators later than the completion of our studies. It is, however, considered that for the period our studies were conducted that they covered the principal periods of spore discharge.

A comparison of spore discharge in the two sections for 1922 and 1923 shows a conspicuous difference as indicated in Figs. I, II, III and IV. The smaller discharge of ascospores in Kent County is not to be explained as the result of any one condition. The later and smaller discharge of ascospores in Kent County is associated with the later maturing of the perithecia in relation to temperature and rainfall. These three conditions are so fluctuating that it is difficult to make any specific correlation. Over a period of years some favorable season may cause a spore discharge in Kent County as great as is found in Sussex County.

The number of spore discharge periods in Kent County were 18 during 1922 and five in 1923 compared with 34 during 1922 and 18 in 1923 for Sussex County. This data further indicates that a greater prevalence of infection should have been found in 1922, which was the situation for both counties. The maximum period of spore discharge for the two years occurred during May in Kent County and during April in Sussex County. Following these periods there is a gradual lessening in frequency and number of ascospores discharged. This condition fortunately follows with the progressive growth

of the tree. This condition is not alone associated with the gradual increase in temperatures but also with the maturity of perithecia and their exhaustion of ascospores.

The lower average of spore discharge in Kent County should be associated with a lower prevalence of infection. During 1923 in order to further support these results a survey of cull apples were made in the two sections. The cull apples from various orchards regardless of spraying practices should indicate whether the lower spore discharge in Kent County is associated with a smaller prevalence of infection. The results of this survey on the Stayman variety of apple, which is a good indicator because of its susceptibility to apple scab, is given in Table I. While may factors may be said to enter into the value of such data, it is considered that the differences are so great as to entertain a reasonable degree of error and still be closely correlated with the smaller spore discharge in Kent County.

Table I

The Prevalence of Diseases and Insect Pests on Cull Apples, 1923

	Kent County	Sussex County
Scab	7 %	60.5%
Codling Moth	72.5%	6 %
Sooty Blotch	4 %	1.5%
Black Rot	5 %	2 %
Curculio	3 %	2 %
Russeting	62 %	14.1%

Ascospore Discharge in Relation to Temperature and Rainfall

Apple scab is generally considered a cool weather disease. It was found that low temperatures were consistently associated with spore discharge. In several instances discharge of spores occurred even with periods of minimum freezing temperatures. It is during the optimum temperature in a single day when moisture conditions are favorable that spore discharges are usually found. It is difficult to find the determining temperature factors over such a period of time as they are important not only to spore discharge but also for infection and growth development. The mean temperature for the period the studies were conducted were found to be lower for 1922 than 1923 when infection and spore discharge were greater. A slow growing season as the result of low temperatures would be favorable for greater leaf infection as the young developing leaves are the most subject to infection. Rapid maturing leaves are not exposed so long to infection and at maturity are quite resistant.

Spore discharge is most consistently associated with periods of rain. Rainfall in April and May is usually associated with the heaviest periods of spore discharge. It was found for both years that the rainfall was greater in Sussex County than Kent County during April and May. However, it must be considered that the total rainfall for any given period is not the deciding factor in spore discharge as much as is the distribution of rainfall.

Ascospore Discharge in Relation to the Growth Stages of the Apple

Ascospore discharge and growth development of apple trees are closely related to temperature and moisture conditions. All four conditions fluctuate considerably even over a period of years. Because of this situation, it is impossible to draw any conclusion during one season that would apply to or be similar to the following season. It is impossible to predict sufficiently ahead of time the influence of moisture and temperature on the discharge of ascospores that would be of value in practical applications of sprays. It is possible, however, to point out certain relations of growth and ascopore discharge that have had a direct relation to control measures.

The growth stages of the apple tree are indicated under the subject of Time of Spray Applications in Figs. I, II, III and IV. It is interesting to note that the period of maximum spore discharge during 1922 and 1923 occurred after the petal fall stage in Kent County and previous to the petal fall stage in Sussex County. This information is further summarized in Table II along with the interval of time between spray applications. The dates for spray applications represent the time such sprays were started but do not pertain to any particular single variety of apple with respect to its stage of development.

Growth conditions were earlier and extended over a longer period between the delayed dormant and pink stage in the Seaford community as compared with Woodside, while between the pink and petal fall stage the reverse conditions obtained is true for these communities. The spore discharge periods were greatest between the delayed dormant and petal fall stage in the Seaford Community and were greatest between the petal fall and three weeks' application for the Woodside Community.

Table II

Number of Days and Ascospore Discharge Periods Between Spray Applications

	Delayed Dormant to Pink		Pink to Petal Fall		Petal Fall to Ten Day		Ten Day to 3 Weeks	
	No. days	No. of spore discharges	No. days	No. of spore discharges	No. days	No. of spore discharges	No. days	No. of spore discharges
Seaford								
1922	18	9	9	6	9	5	10	5
1923	15	7	14	4	9	4	9	1
Woodside								
1922	7	0	17	4	10	5	7	7
1923	10	1	18	1	10	2	10	1

Leaf buds "open up" later than blossom buds and the new development of leaves extends over a longer period than blossom buds. This condition of growth development probably accounts for the usual greater prevalence of infection found on the leaves of the shoot growth. The infection is generally found on a number of successive leaves and then follows a number showing no infection. The number of infected leaves or "zone of infection" is an indicator of a spore discharge period. If the time of unfolding of the young leaves was known it would be possible to figure back to the time when the infection approximately occurred. The "zone of infection" is not only associated with spore discharge but also because the leaves making up the "zone of infection" were susceptible to infection at that time and unprotected by a fungicide.

These periods of growth occurring between spray applications produce much unprotected surface area that may be subject to infection. Leaf growth was measured in 1922 selecting leaves in leaf buds that had just "unrolled" at the time of the calyx application. A leaf marker was used and it was found that growth development of young leaves is uniform in all directions. Two weeks after the calyx spray when the next spray application was made the leaves were picked and the increase area of the growth measured. The new growth represented by each of the twenty-four leaves from different leaf buds during this interval of time averaged from 11.6 to 12.88 square centimeters. These observation were made with the Stayman and Jonathan variety of apple.

The progressive growth development also occurs with the fruit. Measurement of apples were made for growth develop-

ment between the two weeks' spray following the calyx application and the second codling moth application (July 7, 1922) which covered a period of approximately eight weeks. Measurements were made with self-recording calipers of the length and breadth of fifty apples of each variety on representative growing parts of the trees. The fruit on the Stayman variety of apple showed the following relation of $\frac{\text{length}}{\text{breadth}}$ in millimeters to start with, minimum $\frac{8}{6}$, maximum $\frac{13}{3}$, and at the end of the period showed a minimum $\frac{33}{33}$, maximum $\frac{47}{63}$, (July 7). On the Jonathan variety, minimum $\frac{9.5}{7}$, maximum $\frac{14}{12}$, and at the end of the period (July 7) minimum $\frac{40}{50}$, maximum $\frac{45}{50}$. The growth of the fruit during this period would naturally result in producing considerable unprotected new growth surfaces. Infection during this interval of time could arise from ascospores as well as summer spores since the fungus was already established upon the leaves in blossom clusters by May 11, 1922.

General Discussion

The frequency and amount of spore discharge is usually found diminishing soon after the first part of May. The gradual diminution of spores is probably to be associated with the exhaustion of the perithecia as well as unfavorable temperature conditions. When this condition has been reached, the infection from earlier spore discharge, has matured summer spores. The apple scab fungus was fruiting on the leaves by May 10, 1922, in Sussex County and May 16, 1922, in Kent County. Infection is generally found during the first part of May in the commercial orchards. The summer spore stage being established will continue to develop and spread the fungus under favorable conditions during the remainder of the season.

From the standpoint of control, it is apparent that the most important point of attack should be to lessen the possibility of spring infection. This is first possible by means of leaf destruction and second by thorough protection of the developing leaves and fruit by fungicides.

Early cultivation is thoroughly practiced by a number of growers who are entirely convinced of its importance. Plowing is much to be preferred to discing as the burying of the leaves is more thoroughly secured. The studies on spore discharge would indicate that orchard plowing should be completed before the first of April. Curtis (1924) in New Zealand reports fifty per cent reduction of twig infection (one diseased leaf being considered sufficient to constitute a dis-

eased twig) where the leaves had been ploughed under in the test block, as compared with the check block of trees. Both blocks of trees in the experiment received similar spray applications. Raking and burning the overwintered leaves is a definite means of destruction but unfortunately is not practical in the commercial orchards. Several orchardists when making their first applications endeavor to spray the leaves on the ground that were not ploughed under. This practice apparently is of some benefit especially if the leaves are wet before being sprayed. Curtis (1924) conducted an experiment to test the value of spraying the dead apple leaves to prevent ascospore discharge. In the block receiving three dead-leaf sprays, there was a reduction of approximately 40 per cent twig infection compared with the check block. "From this experiment, it is concluded that spraying the leaves offers promise of a simple practical means of materially reducing infection. In the ordinary course of events the leaves on the ground, of course, receive an appreciable amount accidentally when the trees are being sprayed. All that would be required in the normal season is that a little extra time should be devoted to coating the dead leaves thoroughly. When the spray is being applied to the fallen leaves, the force of the pump turns the majority of them over, so that they are sprayed on both sides. Applications of the spray three or four days before rain does not necessarily prevent the discharge of living ascospores; maximum effectiveness of the spray is secured only when it is applied immediately after rain."

It is apparent after studying the tables on spore discharge in relation to rainfall and stage of growth development that it is practically impossible to always time sprays correctly. The conditions favoring spore discharge are beyond one's control. They can be predicted to a certain extent. However, it is not possible or practical to attempt spraying on the prediction of weather conditions that may favor all periods of possible spore discharge. It is more practical to observe the appearance of foliage protection in relation to growth development and weather conditions. Especially is this true for the pink and petal fall periods. Thoroughly protecting the early progressive growth development is the most an orchardist can expect to accomplish by spraying or dusting for scab control.

Extreme variations in weather conditions are experienced locally and generally throughout the commercial orchard sections in Delaware. This is associated with proximity to the Delaware River and Bay. Several large commercial orchards are located in so-called "fog-pockets" where the fog carries over for several days at a time. It is obvious that the difficulty of scab control is increased under such conditions. Spray applications based on spore discharge would have to be locally

determined and their practical value is then questionable owing to the frequency of showers. It would be impossible to establish sufficient stations for spore discharge studies to take care of the variable local and general weather conditions in the two counties.

Summary

The variation of scab prevalence in Kent and Sussex Counties as the result of the studies conducted during 1922 and 1923 was associated with the ascospore discharge in relation to prevailing weather conditions. The earlier maturity and ascospore discharge of the fungus in Sussex County is correlated with greater prevalence of the apple scab disease.

Weather conditions govern the maturity and discharge of ascospores associated with the spring infection during April, May, and June. It is not considered that annual ascospore discharge studies would prove a practical guide for predicting spray applications because of the extreme variation in weather found locally and generally in the two counties.

Control of apple scab must continue to be dependent upon the following conditions:

1. Destruction of overwintered leaves before April by ploughing or any other practical means as a supplement to fungicidal control.

2. Spraying any overwintered leaves when making the "delayed dormant," "pink" and "petal fall" applications.

3. Making timely and thorough applications of efficient fungicides for the "delayed dormant," "pink," and "petal fall" and "two week" periods with a dependable spray outfit and using not less than 200 pounds pressure.

4. When possible and where practical endeavor to time all applications before periods of rain.

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